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TECHNICAL REPORT 2353

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BLAST PROPERTIES OF EXPLOSIVES CONTAINING ALUMINUM OR OTHER METAL ADDITIVES (U)

OLIVER E. SHEFFIELD

NOVEMBER 1956

SAMUEL FELTMAN AMMUNITION LABORATORIES
PICATINNY ARSENAL
DOVER, N. J.

ORDNANCE PROJECT TA3-5001G ITEM (A)
DEPT. OF THE ARMY PROJECT 5A04-10-001

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by

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Technical Report 2353

Ordnance Project TA3 5201G Item (A)

Dept of the Army Project 5A04-10-001

Approved:
for D. R. BEEMAN
Acting Director
Samuel Feltman
Ammunition Laboratories

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OBJECT

To determine the explosive and blast characteristics of the RDX/TNT system containing aluminum or other oxidizable matter.

SUMMARY

Open-air blast tests of unconfined one-pound spherical charges show that in 80/20 TNT/metal mixtures zirconium-nickel alloy, zirconium hydride, magnesium-aluminum alloy, and titanium hydride are equal or superior in performance to the aluminum powder normally used. Tests of the RDX/TNT/aluminum system, in proportions permitting castability, have established the optimum proportions to be 50% RDX, 25 - 30% TNT, and 20 - 25% aluminum.

INTRODUCTION

1. Preliminary measurements of the open-air blast characteristics of TNT containing aluminum, various other metals, alloys, or metallic compounds, and of modified Torpex-type compositions of high aluminum content indicated that many of these mixtures deserved further study (Ref 1). The first measurements were made on cast cylindrical charges, 3.3 in. (8.4 cm) in diameter and 1.65 in. (4.2 cm) in height, which contained a 1 in. × 1 in. cylindrical tetryl pellet. The total charge weighed approximately ¾ pound. It was desired that the more promising metal additives be retested in spherical explosive charges (3.25 in. (8.25 cm) diameter) integrally cast with a 1 in. × 1 in. tetryl pellet placed in the geometric center. The spheres were to weigh approximately one pound.

2. It was also desired that the optimum aluminum content in the RDX/TNT/aluminum system (Torpex) be established on both a more theoretical basis and a sound laboratory foundation (Ref 2). The determination of blast characteristics was to serve as a basis for selecting the most powerful formulation in this ternary system.

RESULTS

3. The performance in open-air tests of one-pound bare spherical charges of 80/20 TNT/metal mixtures shows the following metal additives to be equal to or superior to aluminum:

a. Zirconium-nickel alloy

b. Zirconium hydride

c. Magnesium-aluminum alloy

d. Titanium hydride

The relative peak pressure of this binary system is a function of the rate of detonation; thus, higher rates of detonation produce higher peak pressures.

4. Comparison of the effectiveness of

different metal additives in standard Torpex II (42/40/18–RDX/TNT/metal) shows that specification grade aluminum, Type C, Class C (Spec JAN-A-289) or a special fine aluminum powder (6 micron average) will provide more blast than magnesium-aluminum alloy or a coarse granulation aluminum powder. The relative peak pressure of this ternary system appears to be a function of the brisance, since higher sand test values result in higher peak pressures.

5. The optimum aluminum content of the RDX/TNT/aluminum system is between 18 and 25%, depending upon the composition. The maximum blast pressure results when the ratio of RDX/aluminum is between 1.8 and 2.8. For a given system of constant TNT content, which remains in practical proportions for castability, the following are the optimum percentage compositions:

a. 40/40/20–RDX/TNT/Al

b. 45/30/25–RDX/TNT/Al

c. 57/25/18–RDX/TNT/Al

The calculated nRT power of this ternary system indicates aluminum content for maximum performance to be just half the value established by actual peak pressure measurements. These calculations assume that products of detonation and reactions occur in accordance with the Kistiakowsky-Wilson assumptions that:

a. The metal is fully oxidized before any CO is formed.

b. The oxygen remaining is used to burn C to CO, then H to H_2O, and finally CO to CO_2.

c. Any free C remaining is a solid.

d. The metal oxides remain solid unless the calculated adiabatic flame temperature exceeds the boiling point.

6. Study of the volumetric replacement of RDX by aluminum shows that the maximum peak pressure is produced by a single composition of 47.5/27.5/25 RDX/TNT/aluminum. All formulations of approximately 50% RDX, 25 -- 30% TNT, and 20 – 25% aluminum will perform equally well in open-air blast tests. The addition of 5% wax to a Torpex-type composition (RDX/TNT/Al) somewhat decreases blast performance. This mixture (HBX), however, has satisfactory sensitivity and stability characteristics.

DISCUSSION OF RESULTS

7. To measure pressure-time curves or blast characteristics of an explosive generally requires special gages, an electronic-instrumentation system, and at least one pound of explosive charge. These tests are expensive and analyses of test data are time-consuming. In a preliminary evaluation of new explosives it would be highly desirable to correlate those blast characteristics which are relatively difficult to determine with readily determined explosive

characteristics and also with calculated explosive properties. Relationships between sand test values and air blast results have been determined (Ballistic Research Labs Report 477 and others). Many of the relationships between performance (in terms of brisance, power, or ballistic mortar values) and the readily determined or calculated thermochemical properties which have been shown to exist with pure explosives were found inapplicable to TNT-metal mixtures (Ref 1).

8. To find metal additives equal to or better than aluminum in explosives, the blast data for TNT-metal mixtures were obtained (Table 6). The addition of 20% metallic addend was chosen because this percentage approaches the maximum amount which will produce uniform mixtures readily castable in the temperature range normally used for pouring. To compare the relative effectiveness of these experimental charges, the data were converted to average equivalent volume and average equivalent weight by methods previously devised for this purpose (Ref 3) A brief explanation of the method of calculation will make clear its purpose. The peak pressure-distance data for the standard explosive (TNT) and the test explosives (80/20 TNT/metal), when plotted on log-log graph paper, would give a straight line of negative slope. The relative pressure method compares the ratio of the pressure of the test explosive to the pressure of the standard explosive at each test distance. A sufficient approximation results from using an average relative pressure instead, so that comparisons are made at only one point along the curve. Average equivalent weight $(\overline{EW})$ or average equivalent volume $(\overline{EV})$ is defined as the ratio of the weight or volume of a standard explosive (TNT) to the weight or volume of a test explosive that will produce equal impulses or equal pressures at the same distance.

9. In an effort to analyze the data of Table 6 involving TNT plus 20% of various metal additives, relationships were sought between the different blast parameters and the other explosive properties measured. When the data for average relative pressure (foilmeter or target damage values) were plotted as a function of rate of detonation, sand test, or thermochemical values, no simple relationships were found. Similarly no obvious relationships appeared between impulse (pendulum gage) and these same explosive properties. A somewhat better relationship was found between the relative catenary values and the corresponding rates of detonation when the latter were corrected to an arbitrary common density of 1.70 g/cc. These data from Table 6 are shown in Table 1 and graphically in Figure 1.

10. Metal additives equal or superior to aluminum are zirconium-nickel alloy, zirconium hydride, magnesium-aluminum alloy, and titanium hydride (Fig 1). The simple, direct relationship between the open-air relative average catenary value and the relative heat of combustion which occurs when explosives are

TABLE 1

Explosive Properties of 80/20 TNT/Metal Explosives

Explosive	Catenary, Δ psi,[a] (Table 6)	Ratio Test Expl/TNT ($\bar{K}$)	$\overline{EV}$[b]	W/TNT/W Test Expl.	$\overline{EW}$[c]	Rate of Det calc. to d = 1.70 m sec[d]
TNT	23.1	1.00	1.00	1.00	1.00	7122
TNT/Al	24.2	1.05	1.08	0.94	1.02	6440
TNT/Mg-Al alloy	26.3	1.14	1.22	0.96	1.18	6621
TNT/TiH_4	27.5	1.19	1.30	0.88	1.15	6669
TNT/ZrH_4	26.0	1.13	1.20	0.88	1.06	6510
TNT/Sn	23.6	1.02	1.03	0.91	0.93	6377
TNT/Zn	22.9	0.99	0.98	0.86	0.85	6151
TNT/Zr-Ni alloy	24.4	1.06	1.09	0.88	0.96	6367

[a]Duration of positive phase 0.5 msec

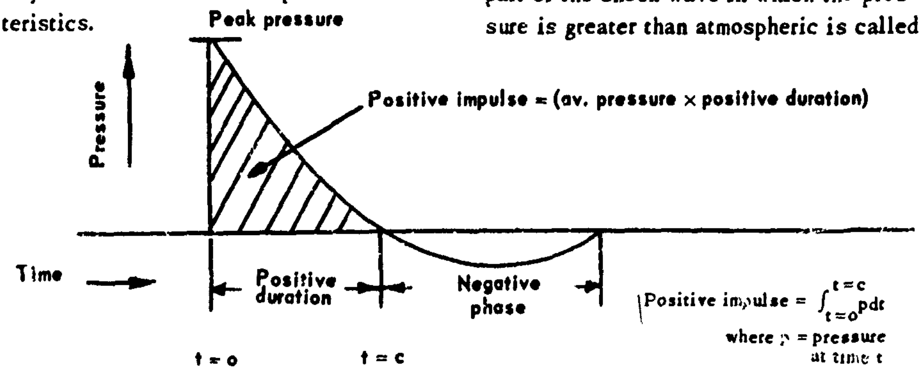
[b]$\overline{EV} = (\bar{K})^{3/2}$ where $\bar{K}$ = Test explosive/TNT

[c]$\overline{EW} = \overline{EV} \times \overline{\text{Weight TNT/Weight test explosive}}$

[d]Equation for correction of rate of detonation of TNT and related binary mixtures for small differences in density (Ref 4): $D_2 = D_1 + 3530\,(d_2 - d_1)$
where D_1 and D_2 are rates of detonation for a given explosive at densities d_1 and d_2

detonated in an enclosed room (Fig 2), is lacking.

11. A view of the propagation of a typical shock wave in air will make clear the various blast parameters measured which may correlate with other explosive characteristics. The drawing below shows that as the shock wave travels outwards from the charge, the pressure decreases steadily to a value below atmospheric pressure and subsequently rises steadily to a value equal to atmospheric pressure. The part of the shock wave in which the pressure is greater than atmospheric is called



Positive impulse = $\int_{t=o}^{t=c} p\,dt$
where p = pressure at time t
and t_c = positive duration

the positive phase, while pressure less than atmospheric is called the negative phase. Positive duration is the time elapsing between arrival of the shock front and that part of the pressure which is exactly equal to atmospheric pressure. Positive impulse is defined above. The catenary diaphragm gage appears capable of measuring the instantaneous peak pressure, whereas the foilmeter and 5-inch NTC blast tube probably measure average pressures. The pendulum gage, which records an integration of pressure-time, measures the positive impulse.

12. Figure 3 shows the relationships between catenary pressure-time values and blast damage (measured by the NFOC-TC compartment gage), peak pressure (measured by the foilmeter), and impulse (measured by the pendulum gage). A direct correlation appears for the metallized TNT explosives (Table 6) and for standard Torpex containing the same percent of different metal additives (Table 7). No correlation appears to exist between the catenary values and other blast characteristics for the RDX/TNT/Al system in varying proportions (Tables 8, 9, and 10). The catenary pressure values were therefore used to evaluate the effectiveness of all the various explosive mixtures.

13. To compare the effectiveness of standard Torpex II with that of compositions containing the same percentages of RDX and TNT but different metal additives, the data from Table 7 were converted to catenary relative pressure values and corrected sand test values as tabulated below:

TABLE 2

Catenary Relative Pressure Values and Corrected Sand Test Values for Torpex and Comparable Systems

Explosive	Catenary, Δ psi,* (Table 7)	Ratio Test Expl/TNT ($\bar{K}$)	$\overline{EV}$**	Sand Test Values: Observed × Cast Density	Sand Test Values: Corrected*** to Volume Basis
60/40 Cyclotol	22.6	1.05	1.08	91.7	88
Std Torpex II	25.5	1.19	1.30	108.3	106
Torpex (coarse Al)	22.5	1.05	1.08	89.2	85
Torpex (fine Al)	25.9	1.20	1.32	106.0	104
Torpex (Mg-Al alloy)	23.7	1.10	1.15	102.3	99
Navy H6 Mix	23.9	1.11	1.17	103.7	101
70/30 Cyclotol	24.1	1.12	1.18	96.8	94
TNT	21.5	1.00	1.00	75.8	70

*Duration of positive phase 0.7 msec.

**$\overline{EV} = (\bar{K})^{3/2}$ where K = test explosive/TNT

***Empirical relationship for converting sand test data obtained on equal weight basis rather than equal volume

$$X = 1.14X' - 16.8$$

where X = sand test × density (volume basis)
and X' = observed sand test × loading density (cast)

No other explosive property data were available for these particular mixtures. Figure 4 shows the direct relationship between sand test and blast pressure. Higher sand test values for a modified Torpex composition reflected the generally greater blast performance of the composition. These data prove 70/30 cyclotol is superior to 60/40 cyclotol, that standard Torpex is superior to the cyclotols, and that fine aluminum powder in the RDX/TNT/Al system will provide more blast than Mg-Al alloy or coarse aluminum powder. The positive phase lasted 0.7 msec for 60/40 and 70/30 cyclotol and 0.7 msec for each modified Torpex composition.

14. Office, Chief of Ordnance has often requested Picatinny Arsenal to determine the optimum aluminum content of castable explosives (Ref 2). Actual peak pressure, impulse data, and experience in military use have shown metallized explosives to be far more efficient blast charges than non-metallized explosives. The effectiveness of aluminum in explosive mixtures is attributed chiefly to the energy evolved in its oxidation, to the resulting over-all volume of gas, and to the pressure developed by the explosive at the unusually high temperatures. The thermodynamic method (calculated nRT) of calculating power has been described in detail (Ref 5). The basis for determining the power or PV work product of an explosive upon detonation is the equation

$$PV = RT\Sigma n$$

where

R = universal gas constant or 1.987 cal/°K/mole

T = adiabatic flame temperature as obtained from

$$T = 298 + \frac{Q_E^V}{\Sigma\, nC_V} \times 10^3 \text{ with}$$

Q_E^V = heat of explosion at constant volume in kcal/mole

n = number of moles of gas formed

C_V = average heat capacity in cal/mole

With the above system, the thermodynamic power obtainable from practical proportions of the Torpex ingredients (RDX/TNT/aluminum) was calculated.

15. These data are shown graphically in Figures 5, 6, and 7. It was hoped that those proportions yielding maximum power in this ternary system would thus be indicated. Formulations of Torpex in which the TNT present is sufficient only to provide the casting medium (25%, Fig 7) appear superior to the standard Torpex formulation (42/40/18 RDX/TNT/aluminum). The calculated nRT power appears to be independent of the RDX/aluminum ratio either on a weight (Fig 8) or volume (Fig 9) basis in the range 4 to 14 RDX/Al. The foregoing brief discussion shows that the optimum aluminum content

of this system is between 0 and 30%.

16. Table 8 lists blast characteristics of the RDX/TNT/Al system in which

a. The TNT is held constant.

b. The aluminum content is increased to 30%.

c. The ratio of RDX/aluminum is varied from 0 to 6.

These data have been grouped below to show the relative peak pressure as a function of the aluminum content and the RDX/aluminum ratio.

The relationship between relative pressure and aluminum content (Fig 10) shows that for a 40% TNT composition, 20% aluminum is optimum; for a 30% TNT composition, 25% aluminum is optimum; and when 25% TNT is used in the composition, 18% is optimum. Figure 11 shows that regardless of the amount of TNT used in the range 25–40%, the maximum blast pressure results only when the ratio of RDX/aluminum is between 1.8 and 2.8. Figures 12, 13, and 14 show further that in a comparison of the calculated nRT power with the determined peak pressure values, the optimum aluminum content calculated is only half of the actual amount determined by experimentation.

TABLE 3

Relative Peak Pressure as a Function of Aluminum Content and RDX/Aluminum Ratio

Explosive (RDX/TNT/Al)	Catenary, Δ psi* Table 8	Ratio Test Expl/TNT ($\bar{K}$)	$\overline{EV}$	Aluminum Content, %	Ratio RDX/Al
60/40/0 Cyclotol	22.6	1.11	1.17	0	∞
49/40/11	24.4	1.20	1.32	11	4.45
42/40/18 Std Torpex	25.5	1.25	1.40	18	2.34
35/40/25	25.0	1.23	1.36	25	1.40
30/40/30	25.1	1.23	1.36	30	1.00
70/30/0 Cyclotol	24.1	1.18	1.30	0	∞
58/30/12	24.8	1.22	1.35	12	4.83
50/30/20	25.8	1.26	1.41	20	2.50
45/30/25	25.9	1.27	1.43	25	1.80
43/27/30**	25.6**	1.25	1.40	30	1.43
75/25/0 Cyclotol	24.2	1.19	1.30	0	∞
64/25/11	25.0	1.23	1.36	11	5.81
55/25/20	26.3	1.29	1.47	20	2.75
50/25/25	26.0	1.27	1.43	25	2.00
47.5/22.5/30**	25.3**	1.24	1.38	30	1.58
TNT	20.4	1.00	1.00		

*Duration of positive phase 0.5 msec

**Composition and catenary values taken from Tables 9 and 10

It can be concluded that in the RDX/TNT/Al system the optimum aluminum content is between 18 and 25%, depending on the TNT content, and that 25% TNT provides a system of maximum peak pressure. These results agree with open-air blast measurements of 9-lb charges, which established the optimum aluminum content in the RDX/TNT/Al system at 20 to 28%, the percentage depending on whether pressure, impulse, weight, or volume of charge was of primary interest (Ref 6). Earlier British work (Ref 7) had found that an aluminum concentration of 30% gave greatest blast intensities.

17. Since RDX is among the most powerful standard explosives at present, it is desirable that its content in ternary mixtures should be as high as possible and still give castable compositions of high density. Office, Chief of Ordnance (Ref 2) prefers a volumetric replacement of RDX by aluminum to weight replacement, since the former replacement is not expected to affect the viscosity adversely. On the basis of calculations of volumetric aluminum replacement of RDX the compositions listed in Tables 9 and 10 were recommended for tests to establish the optimum aluminum content (Ref 2). The blast test results given in Tables 9 and 10 have been reduced to relative peak pressure values as shown below.

TABLE 4

Relative Peak Pressure Values for RDX/TNT/Al Compositions

Explosive** RDX/TNT/Al		Catenary, Δ psi,* Tables 9 and 10	Ratio Test Expl/TNT ($\bar{K}$)	$\overline{EV}$	Ratio RDX/Al
70/30/0 Cyclotol	(1)	24.1	1.09	1.16	∞
61/29/10	(2)	25.1	1.14	1.22	6.10
52/28/20	(3)	25.6	1.16	1.25	2.60
47.5/27.5/25	(4)	25.9	1.17	1.26	1.90
43/27/30	(5)	25.6	1.16	1.25	1.43
34/26/40	(6)	25.8	1.17	1.26	0.85
75/25/0 Cyclotol	(7)	24.2	1.10	1.15	∞
66/24/10	(8)	24.4	1.10	1.15	6.60
56.5/23.5/20	(9)	25.7	1.16	1.25	2.82
52/23/25	(10)	25.7	1.16	1.25	2.08
47.5/22.5/30	(11)	25.3	1.14	1.22	1.58
38/22/40	(12)	25.2	1.14	1.22	0.95
TNT		22.1	1.00	1.00	1.00

*Duration of positive phase not reported

**Numbers in parentheses following composition refer to base line points on graph of Figure 15

Since these formulations have three variables with no ingredient held constant, a plot of the proportion of the ingredients, on a basis of either weight or volume, assumes significance on triangular coordinate paper only when an additional variable, such as performance or power, is plotted along an axis at right angles to the plane of the triangle.

18. Figure 15 shows a three-dimensional diagram of these data plotted as a function of the relative peak pressure. This figure indicates that maximum peak pressure is produced by a composition of

50% RDX
25 - 30% TNT
20 - 25% Aluminum

This conclusion agrees with the results found in Table 8. In this series the single composition giving the best performance with respect to blast characteristics is 47.5/27.5/25 RDX/TNT/aluminum.

19. Because of the Ordnance Corps growing interest in castable high-blast explosives, it was also considered desirable to test HBX type explosives, now standardized by the Department of the Navy. HBX explosives were developed as relatively insensitive mixtures by adding 5% desensitizing wax to Torpex II, an Army service explosive. The D-2 desensitizing wax is a mixture of 84% hydrocarbon wax, 14% nitrocellulose, and 2% lecithin. HBX-1 is HBX (Torpex II + 5% D-2 wax) to which 0.5% by weight of calcium chloride has been added. A program initiated to improve the performance of HBX by increasing the ratio of RDX/TNT and increasing the aluminum content yielded mixtures designated HBX-3 and HBX-6 (Ref 8). The detonation velocity varied inversely with increased aluminum content and appeared independent of the RDX/TNT ratio. Some explosive properties, including blast characteristics of the HBX explosives, are listed in Table 11. The relative catenary peak pressure values ($\overline{EV}$= 1.18, 1.23, and 1.23 respectively) show that HBX-3 of high aluminum content (35%) is not superior in performance to HBX-6 of 20% aluminum. HBX-1 is slightly less effective than the other HBX mixtures in open-air performance.

20. It was desired to determine the results of detonation by two different methods of initiation and to ascertain whether the No. 8 electric detonator can give consistent high-order detonations. Therefore, 5 of the TNT and 5 of the HBX-1 charges were initiated by U. S. special blasting caps and the results compared with the results of initiation by No. 8 electric detonators as shown in Table 5. Data in this table show that the No. 8 electric detonator provided sufficient energy for initiation of the tetryl booster and high-order detonation of the explosive charge.

21. Future work in evaluating the blast performance of metallized explosive charges might be directed towards a review of the existing theories

TABLE 5

Results of Initiation by Electric Detonators
and Special Blasting Caps

HE Charge	Initiator	Rounds	Impulse	Open-Air Blast Tests Foilmeter, psi	5-in NTC	Catenary, psi
TNT	No. 8 Electric Detonator	10	16.1	7.5	4.7	23.1
		10	15.8	8.1	4.8	21.5
		10	16.8	8.0	4.6	20.4
		1	18	8	6	—
		2	17.5	8	5	22
		3	16	8	5	22
		4	16.5	8	4	22
		5	16	8	7	22
TNT	Special Blasting Cap	1	17	8	6	21
		2	16	8	5	22
		3	16.5	8	4	22
		4	16.5	8	3	24
		5	16	8	4	22
HBX-1	No. 8 Electric Detonator	1	22.5	9	6	—
		2	18	9	7	24
		3	18.5	10	6	27
		4	19	9	7	24
		5	19.5	10	7	24
HBX-1	Special Blasting Cap	1	20.5	8	7	26
		2	19.5	9	7	24
		3	19	9	7	23
		4	20	8	5	25
		5	19.5	10	6	25

regarding the behavior of shock waves, an analysis of existing experimental work, and the development of equations which would make possible the prediction of damage to be expected from the various standard and experimental explosive fillers.

EXPERIMENTAL PROCEDURE

22. The characteristics of the ingredients used in this study are as follows:

a. RDX: Holston Lot 6-17 used in compositions of Tables 7, 8, and 9 and Holston Lot DAC-501 used in compositions of Table 10 both complied with Specification JAN-R-398 for Type B, Class A material.

b. TNT: both Volunteer Lot 3615 used in all compositions except 147-195-A, B, C, and D and TNT Lot KNK-7-483 used in those 4 compositions complied with Specification JAN-T-248 for Grade I material.

c. The atomized aluminum used in all compositions was Reynolds Metal Company Lot 918, Type C, Class C material complying with the granulation requirements of Specification JAN-A-289.

d. The Dow Chemical Company spherical aluminum designated as "coarse" showed the following granulation:

US Std Sieve No.	% Passing Through
12	100
20	99
40	83
100	30
200	8
230	5
325	3

e. The special granulation aluminum designated as "fine" had an average particle size of 6 microns.

f. The 65/35 magnesium-aluminum alloy, Type B, complied with the requirements of Specification JAN-M-454.

g. All other metals, alloys, or metal compounds complied with the existing specifications and were granulated to pass 100% through a U. S. std sieve No. 100.

Preparation of Spherical Charges

23. Ten charges of approximately one pound each were prepared in the experimental HE loading plant by cast loading the explosive mixtures at the lowest practical pour temperature. The mold for these spherical charges of 3.25-inch diameter is shown in Picatinny Arsenal Drawing SK-43375, 12/16/50. Each charge was precision-cast to control the depth of the detonator well at 2.125 ±0.025-inch by 0.315-inch diameter. A tetryl pellet, 1 inch × 1 inch, with a 0.315-inch diameter hole through its center was located in the geometric center of the mold before casting.

Cast Density

24. Each charge was weighed to the nearest gram and the cast density of the explosive was calculated based on a volume of 292 cc, the space actually occupied by the explosive.

Open-Air Blast Tests

25. The static open-air blast tests of the subject charges were conducted under Contract DAI-19-020-501-ORD (P)-58 by National Northern, Division of National Fireworks Ordnance Corp., at the Halifax Range. This site has a quad-instrument arrangement for detecting the blast from a single charge. Details of the site are reported in National Northern Report NN-P-30, "Blast Evaluation of Bare and Cased Charges," July 1955. The test charge was placed 9 feet above ground level with the cap cavity facing up. Most of the charges were initiated by the No. 8 electric detonator. Some were initiated by the M36 detonator and by the special blasting cap to determine if different methods of detonation are comparable.

The results of these tests are discussed in the text (Par 20).

Test Equipment and Gages

26. Four gages, each in a different quadrant, were located at various distances from the charge. Each gage was placed to receive only the free-air blast (incident) wave, that is, without reinforcement from reflected or Mach waves. The four blast detectors were as follows:

a. Pendulum Gage—290 lb in weight and 2 feet square, placed 3 feet from the charge center. Designed by National Northern to record an integration of pressure-time.

b. Catenary Diaphragm—placed 6 ft 8 in. from the charge center Developed to record pressure-time side-on to the blast wave.

c. Foil Meter—foil of 0.0?5-inch S aluminum. National's modification of the Bikini gage us[illegible] to record peak pressure, face-on to the blast front at 5 feet from the charge center.

d. 5-inch N-T-C—designed by National Northern as a possible means of correlaing blast with aircraft damage beyond the kill area This gage is 5 inches in diameter, faces the charge, and has tubular steel compartments 6 inches in length with 0.0025-inch aluminum foil between compartments. The face of the No. 1 compartment is placed 6 feet from the charge center.

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7. *Blast Performance of Torpex Mixtures Containing 0-42 Percent of Aluminum,* Ministry of Supply, Armament Research Department, ARD Explosives Report 22/45 (AC 8131/SD 543), March 1945

8. S. R. Walton, *Report on the Program to Develop an Improved HBX Type Explosive,* NAVORD Report 1502, 26 July 1950

TABLE 6
Characteristics of TNT Containing Various Metal Additives

Composition No:	147-195-A	147-195-B	147-195-C	147-195-D	147-195-E	147-195-F	147-195-G	147-195-H
Composition, %*								
TNT	100	80	80	80	80	80	80	80
Aluminum (Atomized)	—	20	—	—	—	—	—	—
Mg-Al Alloy, 65/35	—	—	20	—	—	—	—	—
Titanium Hydride	—	—	—	20	—	—	—	—
Zirconium Hydride	—	—	—	—	20	—	—	—
Tin	—	—	—	—	—	20	—	—
Zinc	—	—	—	—	—	—	20	—
Zirconium-Nickel Alloy	—	—	—	—	—	—	—	20
Cast Density, g/cc (Calc. Assuming Volume 292 cc)	1.58	1.67	1.63	1.78	1.79	1.74	1.83	1.78
Impact Test, PA APP								
2 Kg Weight, in.	14-15	13	10	11	13	12	12	10
Wt of Charge, g	0.017	0.014	0.015	0.017	0.015	0.019	0.024	0.016
200 g Bomb Sand Test**								
Sand Crushed, g	48.0	49.8	30.0	44.2	44.7	40.8	41.4	43.4
Initiator, g								
Lead Azide	0.27	0.30	0.20	0.20	0.20	0.24	0.28	0.30
Tetryl	0.20	0.00	0.10	0.05	0.10	0.00	0.00	0.00
Rate of Detonation**								
(Drum Camera) m/sec	6708	6475	6621	6881	6651	6619	6366	6438
Density, g/cc	1.58	1.71	1.70	1.76	1.74	1.78	1.76	1.72
Free-Air Blast Test, 3.25-in. Diam Spherical Chg								
Peak Pressure, psi (Foil Meter)	7.5 (8)	8.0 (6)	7.8 (6)	8.3 (4)	7.7 (3)	7.8 (10)	7.7 (9)	8.0 (5)
Impulse (Pendulum)	16.1 (8)	18.2 (6)	17.3 (6)	17.9 (4)	17.7 (3)	16.4 (10)	16.5 (9)	16.9 (5)
Damage (NFOC-TC)	4.7 (8)	4.7 (6)	5.8 (6)	5.5 (4)	5.2 (3)	4.3 (10)	4.4 (9)	5.0 (5)
Catenary, Δ psi	23.1 (8)	24.2 (6)	26.3 (6)	27.5 (4)	26.0 (3)	23.6 (10)	22.9 (9)	24.4 (5)
Weight of Chg, g (Avg of 10)	460 (50)	488	477	521	523	507	533	521
Average Deviation	±1.7	±4.3	±2.5	±2.2	±4.1	±21.0	±7.6	±19.9

*See Experimental Procedure for a description of materials
**Data taken from Picatinny Arsenal Memorandum Report 44, 30 September 1953 (Ref 1)

TABLE 7
Characteristics of Cyclotol Containing Various Metal Additives

Composition No:	147-195-O	147-195-I	147-195-J	147-195-K	147-195-L	147-195-M	147-195-S	147-195-A
Composition, %*	Cyclotol	Std Torpex II				Navy Mix	Cyclotol	
RDX, HOL Lot-6-17	60	42	42	42	42	47	70	—
TNT, Vol Lot-3615	40	40	40	40	40	31	30	100
Aluminum (Atomized)	—	18	—	—	—	22	—	—
Aluminum, (Coarse)	—	—	18	—	—	—	—	—
Aluminum (Fine)	—	—	—	18	—	—	—	—
Mg-Al Alloy, 65/35	—	—	—	—	18	—	—	—
D2 Wax, Added	—	—	—	—	—	5	—	—
Cast Density, g/cc (Calc. Assuming Vol. 292 cc)	1.68	1.77	1.77	1.79	1.71	1.70	1.71	1.58
Impact Test, PA APP**								
2 Kg. Wt, in.	14	14	6	8	9	14	14***	14
Wt. of Charge, G	0.019	0.024	0.025	0.021	0.020	0.018	0.020	0.017
200 G Bomb Sand Test**								
Sand Crushed, G	54.6	61.2	50.4	59.2	59.8	61.0	56.6***	48.0
Initiator, G								
Lead Azide	0.20	0.30	0.30	0.20	0.30	0.30	0.20	0.27
Tetryl	—	0.00	0.00	0.06	0.00	0.00	—	0.20
Mercury Fulminate	0.22						0.21	
Free-Air Blast Test, 3.25-In. Diam. Spherical Charge								
Peak Pressure, psi (Foil Meter)	9.1 (10)	9.6 (8)	9.2 (10)	9.1 (7)	9.1 (10)	9.[illegible] (10)	9.0 (10)	8.1 (10)
Impulse (Pendulum)	18.9 (10)	20.8 (8)	19.4 (10)	21.4 (7)	19.6 (1[illegible])	20.0 (10)	19.6 (10)	15.8 (10)
Damage (NFOC-TC)	6.4 (8)	7.4 (8)	6.4 (9)	6.7 (7)	6.5 (10)	6.5 (10)	6.4 (10)	4.8 (9)
Catenary, Δ psi	22.6 (10)	25.5 (8)	22.5 (6)	25.9 (7)	23.7 (10)	23.9 (9)	24.1 (7)	21.5 (7)
Weight of Chg, g (Avg of 10)	491	518	518	524	500	495	500	460
Avg Dev.	±0.7	±1.9	±3.1	±2.4	±1.4	±6.1	±0.7	

*See Experimental Procedure for a description of materials
**Data taken from Picatinny Arsenal Memorandum Report 44, 30 September 1953 (Ref 1)
***Data taken from Picatinny Arsenal Technical Report 1740, 20 June 1949

TABLE 8

Characteristics of the RDX/TNT/Al System in Practical Proportions as Related to Performance

Composition No:	147-195-O	147-195-P	147-195-I	147-195-R	147-196-A	147-195-S	147-195-T	147-195-U	147-196-B	147-195-V	147-195-W	147-195-X	147-196-C	147-195-A
Composition, %	Cyclotol		Std Torpex II			Cyclotol				Cyclotol				
RDX,HOL Lot 6-17	60	49	42	35	30	70	58	50	45	75	64	55	50	---
TNT, VOL Lot 3615	40	40	40	40	40	30	30	30	30	25	25	25	25	100
Aluminum (Atomized)	---	11	18	25	30	—	12	20	25	—	11	20	25	—
Cast Density G/cc (Calc Assuming Volume 292 cc)	1.68	1.75	1.77	1.77	1.82	1.71	1.75	1.78	1.79	1.72	1.68	1.75	1.79	1.58
Impact Test, PA APP														
2 Kg Weight, in.	14		14			14								14
Wt of Charge, G	0.019		0.024			0.020								
200 g Bomb Sand Test														
Sand Crushed, G	54.6		61.2			56.6								48.0
Initiator, G														
Lead Azide	0.20		0.30			0.20								0.27
Tetryl	---		0.00			—								0.20
Mercury Fulminate	0.22					0.21								
Free-Air Blast Test, 3.25-in. Diam Spherical Chg														
Peak Pressure, psi (Foil Meter)	9.1 (10)	9.1 (9)	9.6 (8)	9.3 (9)	9.1 (10)	9.0 (10)	9.3 (10)	9.6 (10)	9.3 (10)	9.0 (10)	9.3 (10)	9.3 (9)	9.6 (10)	8.0 (10)
Impulse (Pendulum)	18.9 (10)	21.6 (10)	20.8 (8)	19.6 (10)	21.3 (10)	19.6 (10)	21.7 (10)	21.7 (10)	21.8 (10)	20.5 (10)	21.2 (10)	22.0 (10)	21.9 (10)	16.8 (9)
Damage (NFDC-TC)	6.4 (8)	6.2 (9)	7.4 (8)	6.1 (10)	6.7 (10)	6.4 (10)	6.5 (9)	6.4 (10)	5.7 (10)	6.0 (10)	6.2 (10)	6.7 (10)	7.5 (10)	4.6 (10)
Catenary, Δ psi	22.6 (10)	24.4 (8)	25.5 (8)	25.0 (10)	25.1 (9)	24.1 (7)	24.8 (9)	25.8 (10)	25.9 (9)	24.2 (9)	25.0 (8)	26.3 (10)	26.0 (10)	20.4 (9)
Weight of Chg g (Avg of 10)	491	510	518	516	532	500	512	519	522	501	491	[illegible]12	523	460 (50)
Avg Deviation	±0.[illegible]	±1.5	±1.9	±3.3	±4.9	±0.7	±2.5	±4.1	±1.9	±0.7	±3.6	±[illegible].7	±4.1	±1.7
Calculated nRT Power: TNT = 100	135	142	133	118	99	140	149	139	125	143	154	141	127	

TABLE 9
Characteristics of Compositions Suggested by OCO for Tests

Composition No:	147-195-S	147-197-B	147-197-C	147-197-D	147-197-E	147-197-F	147-197-G	147-195-A
Composition, %	(a)	(b)	(c)	(d)	(e)	(f)	(g)	
RDX, HOL 6-17	70	61	52	47.5	43	34	25	—
TNT, VOL-3615	30	29	28	27.5	27	26	25	100
Aluminum, (Atomized)	—	10	20	25	30	40	50	—
Cast Density, G/cc (Calc Assuming Volume 292 cc)	1.71	1.73	1.81	1.85	1.88	..92	Not pourable	1.58
Impact Test, PA APP								
2 Kg Weight, In.	14							14
Wt of Charge, G	0.020							
200 G Bomb Sand Test								
Sand Crushed, G	56.6							48.0
Initiator, G								
Lead Azide	0.20							0.27
Tetryl	—							0.20
Mercury Fulminate	0.21							—
Free-Air Blast Test, 3.25-In. Diam Spherical Chg								
Peak Pressure, psi (Foil Meter)	9.0 (10)	9.1 (10)	9.1 (10)	9.4 (10)	9.3 (10)	9.3 (10)	—	8.0 (10)
Impulse (Pendulum)	19.6 (10)	19.9 (10)	21.7 (10)	21.9 (10)	22.1 (9)	21.0 (9)	—	16.6 (10)
Damage (NFOC-TC)	6.4 (10)	6.2 (10)	7.2 (10)	7.2 (10)	7.0 (10)	7.2 (10)	—	4.9 (10)
Catenary, Δ psi	24.1(7)	25.1 (9)	25.6 (9)	25.9 (8)	25.6 (9)	25.8 (8)	--	22.1 (9)
Weight of Chg, G (Avg of 10)	500	504	528	540	550	561	—	460 (50)
Avg Dev	±0.7	±6.5	±2.0	±1.8	±2.1	±2.4		±1.7

TABLE 10

Characteristics of Compositions Suggested by OCO for Tests

Composition No:	147-195-V	147-197-I	147-197-J	147-197-K	147-197-L	147-197-M	147-197-N
Composition, %*	(h)	(i)	(j)	(k)	(l)	(m)	(n)
RDX, OAC-501	75	66	56	52	47.5	38	29
TNT, VOL-3615	25	24	23.5	23	22.5	22	21
Aluminum (Atomized)	—	10	20	25	30	40	50
Cast Density, g/cc (Calc Assuming Volume 292 cc)	1.72	1.73	1.81	1.86	1.81	1.89	Not pourable**
Impact Test, PA APP							
2 Kg Weight, In.	18	—	—	16-18	—	—	—
Wt of Charge, G	0.018	—	—	0.018	—	—	0.020
Friction Pendulum Test Steel Shoe, 10 Trials							
Crackles	0			10			2
Sparks	0			1			0
Detonation	0			0			0
Unaffected	10			0			8
Free-Air Blast Test, 3.25-In Diam Spherical Chg							
Peak Pressure, psi (Foil Meter)	9.0 (10)	9.1 (9)	9.4 (10)	9.9 (10)	9.8 (10)	9.3 (10)	—
Impulse (Pendulum)	20.5 (10)	20.0 (9)	21.9 (10)	21.3 (10)	20.9 (10)	21.0 (10)	—
Damage (NFOC-TC)	6.0 (10)	6.4 (9)	6.8 (10)	6.9 (10)	7.0 (10)	6.9 (10)	—
Catenary, Δ psi	24.2 (9)	24.4 (5)	25.7 (9)	25.7 (9)	25.3 (9)	25.2 (9)	
Weight of Chg, G (Avg of 10)	501	505	529	542	529	552	
Average Deviation	±0.7	±6.1	±5.3	±7.1	±2.7	±5.0	—

*Prepared from 75/25 Cyclotol (Lot WVW 2862) and Type C, Atomized aluminum of 200 mesh
**Density of 1.69 gm/cc considered low because of voids in the charge

TABLE 11

Characteristics and Explosive Properties of HBX Compositions

Composition (by weight)	HBX-1	HBX-3	HBX-6	TNT
RDX, Type B, Class A	40	31	45	—
TNT, Grade I	38	29	30	100
Al, Atomized, Type C, Cl.c	17	35	20	—
D-2 Wax	5	5	5	—
Calcium Chloride (100 mesh)	0.5	0.5	0.5	—
Impact Test, PA App				
2 kg wt, inches	16	15	14	14
Wt of Charge g	0.021	0.023	0.018	0.017
Explorrtory Sand Test				
Sand Crushed, g	59.2	51.6	61.0	48.0
Min Detonating Chg, g				
Lead Azide	0.20	0.20	0.30	0.27
Tetryl	0.05	0.10	0.00	0.20
Explosion Temp. Test, °C	480	500	610 (min)	475
100°C Vac Stab Test				
cc gas evolved /40 hours	0.47	0.45	0.47	0.10
Rate of Detonation				
Drum Camera, m/sec	7224	6917	7191	6708
Density, g/cc	1.69	1.81	1.71	1.58
Free- Air Blast Test				
3.25-in. Diam Spherical Chg				
Peak Pressure, psi				
(Foil Meter)	9.1 (10)	9.2 (10)	9.4 (10)	8.0 (10)
Impulse (Pendulum)	19.6 (10)	20.6 (10)	19.8 (10)	16.6 (10)
Damage (NFOC-TC)	6.5 (10)	6.7 (10)	6.7 (10)	4.9 (10)
Catenary, Δ psi	24.7 (9)	25.5 (9)	25.4 (9)	22.1 (9)
Wt of Chg g (Avg of 10)	494	528	500	460 (50)
Average Deviation	±5.1	±3.1	±4.3	±1.7

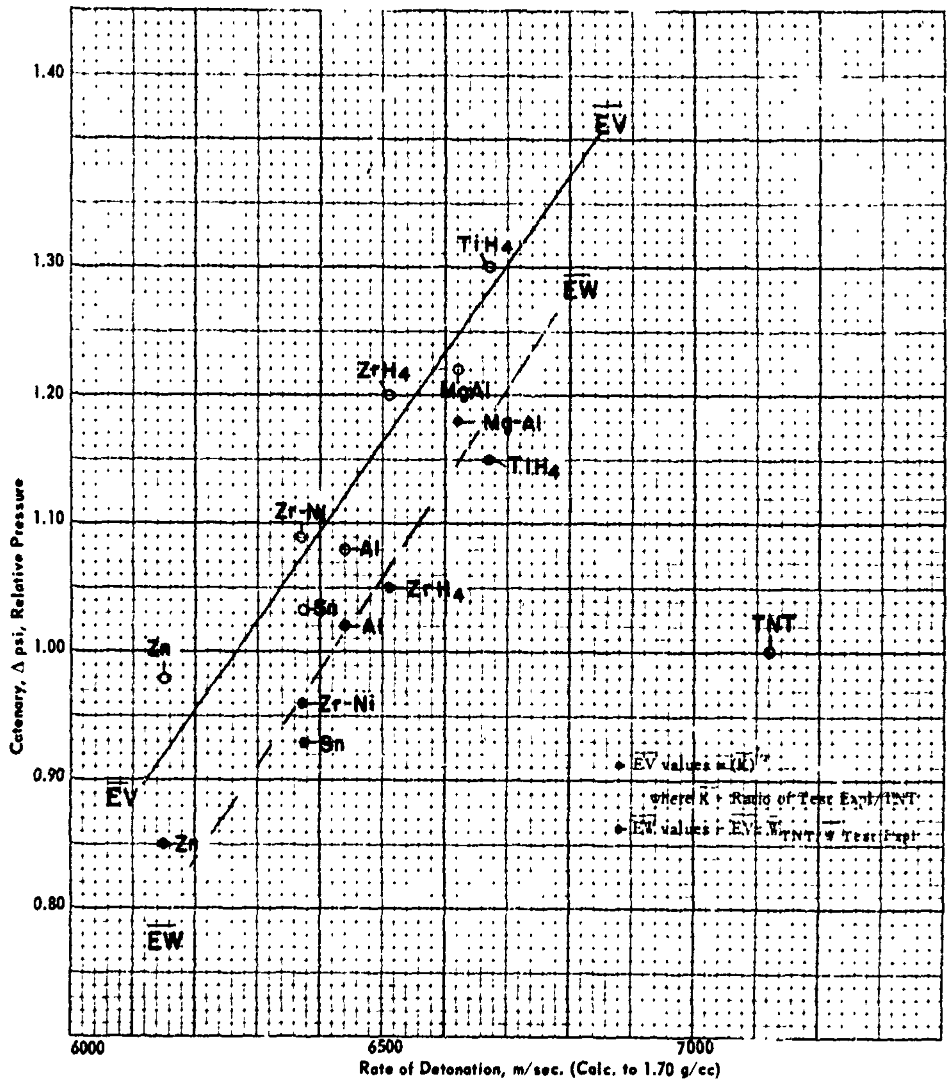

Fig 1 Empirical Relationship between Catenary, Δ psi, Blast Data of Bare Spherical Charges and Rate of Detonation for 80/20 TNT/Metal Mixtures

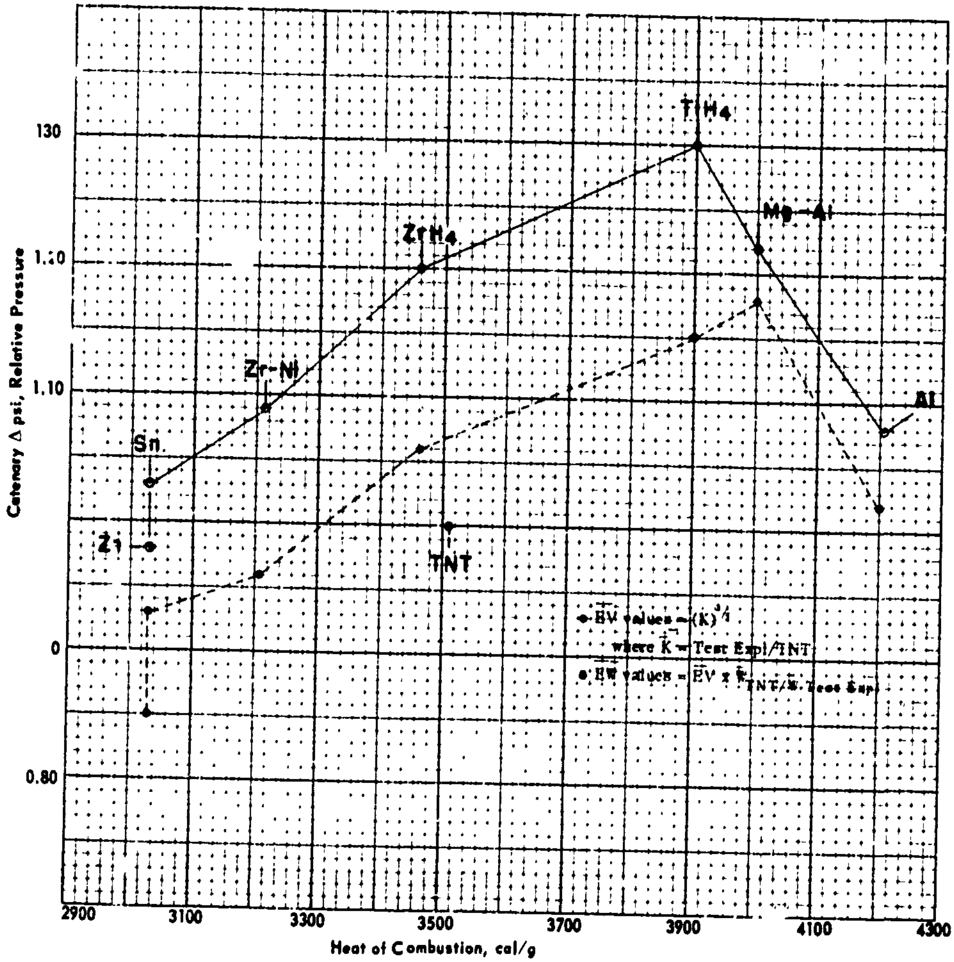

Fig 2 Relationship between Relative Pressure, Catenary, Δ psi, and Heat of Combustion, (cal/g) for 80/20 TNT/Metal Mixtures

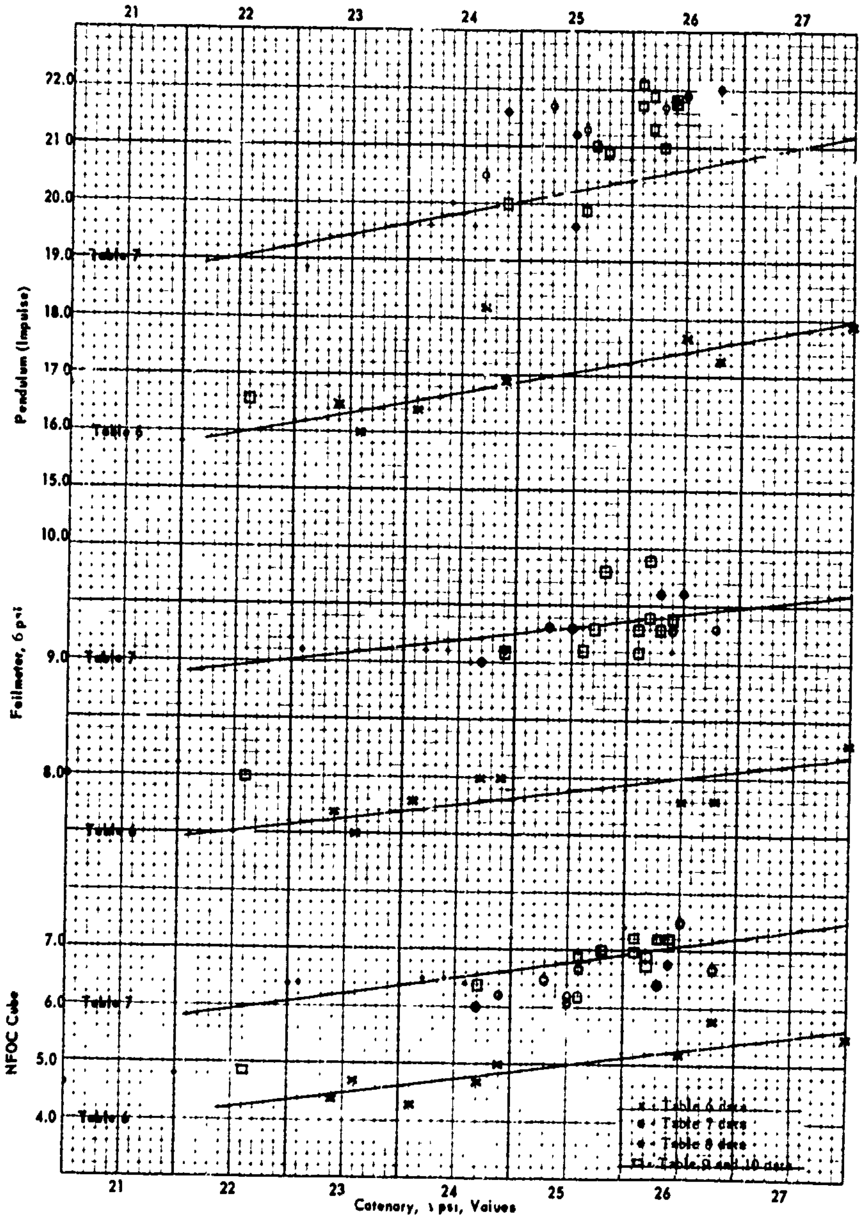

Fig 3 Relationship between Catenary Pressure and Other Blast Parameters Measured

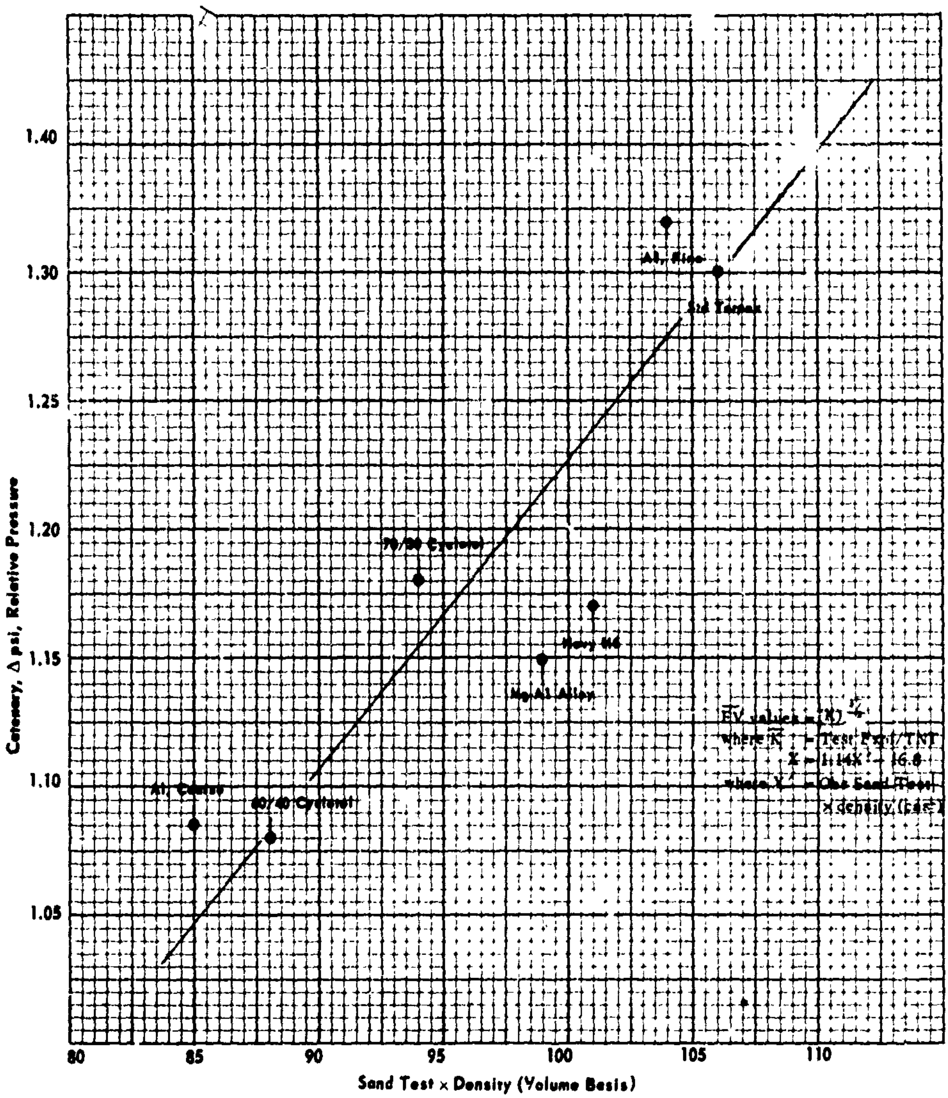

Fig 4 Empirical Relationship between Catenary, Δ psi, Blast Data of Bare Spherical Charges and Sand Test Values for Metallized Cyclotol

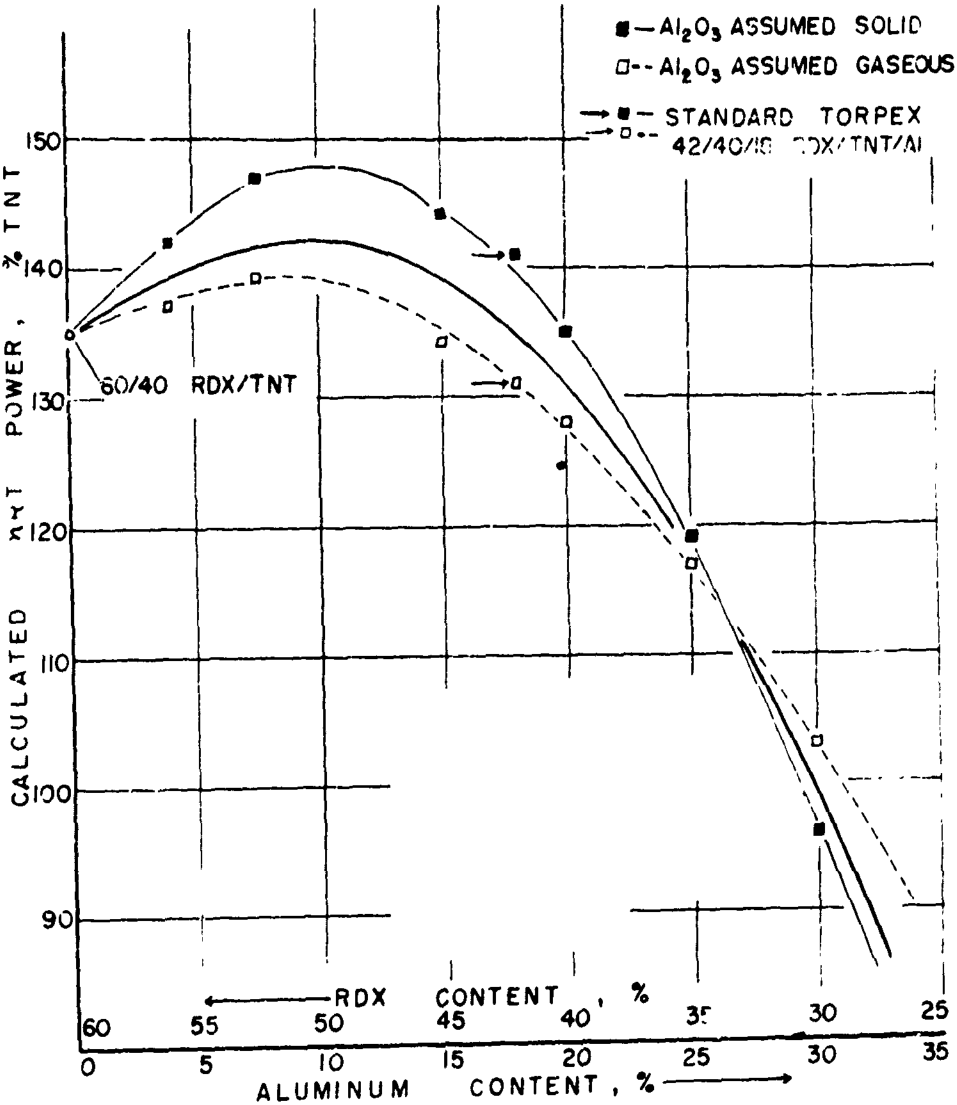

Fig 5 Maximum nRT Power Obtainable from Torpex Basic Mixture with TNT Constant at 40% by Weight

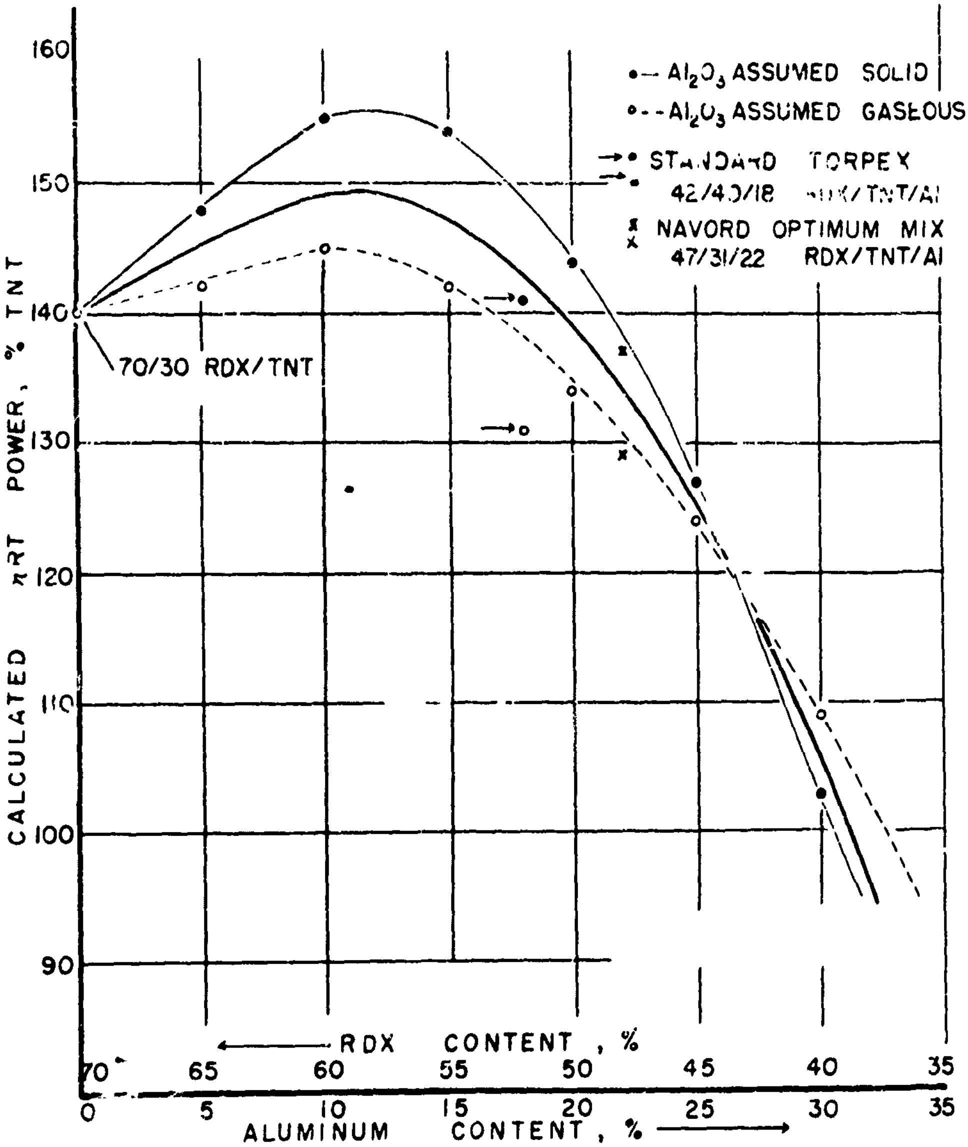

Fig 6 Maximum nRT Power Obtainable from Torpex Basic Mixture with TNT Constant at 30% by Weight

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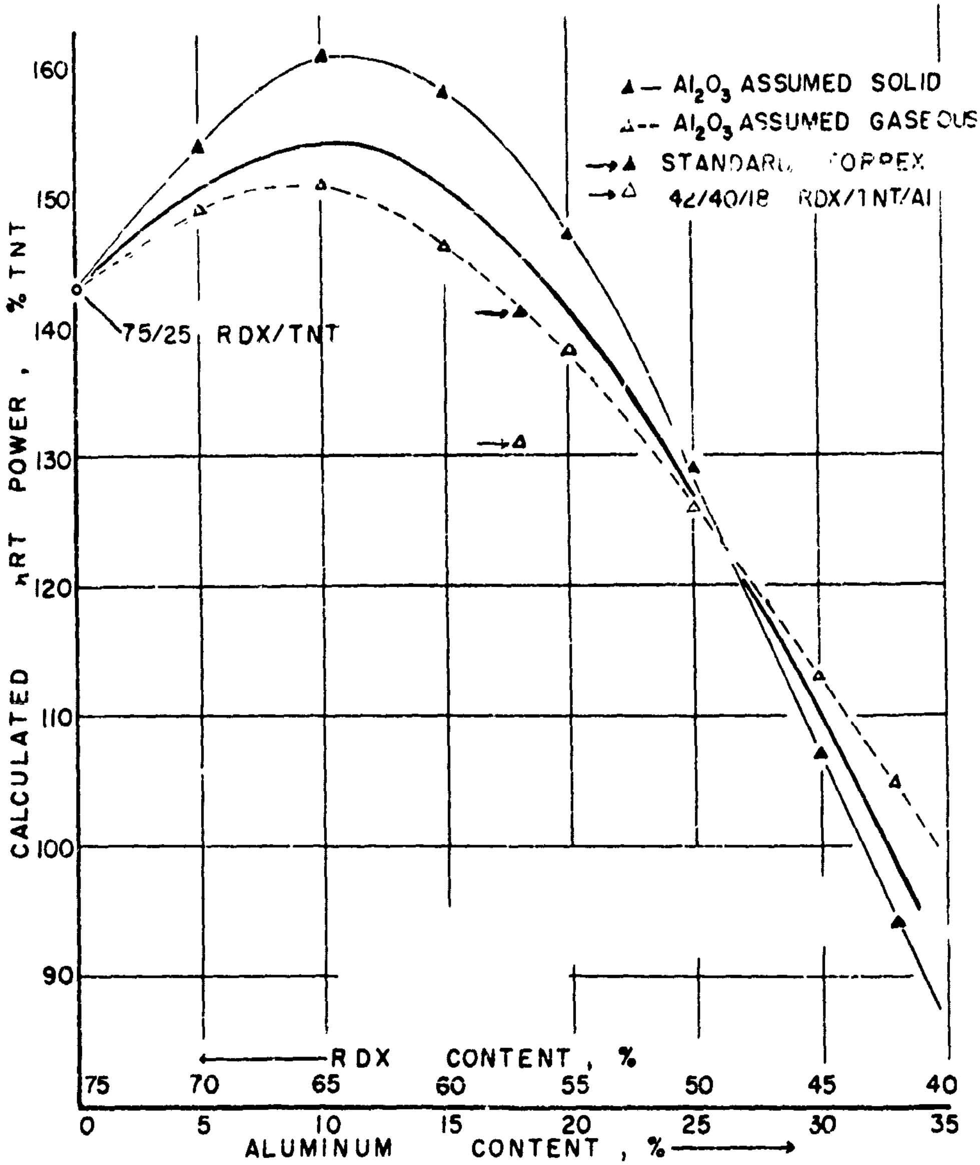

Fig 7 Maximum nRT Power Obtainable from Torpex Basic Mixture with TNT Constant at 25% by Weight

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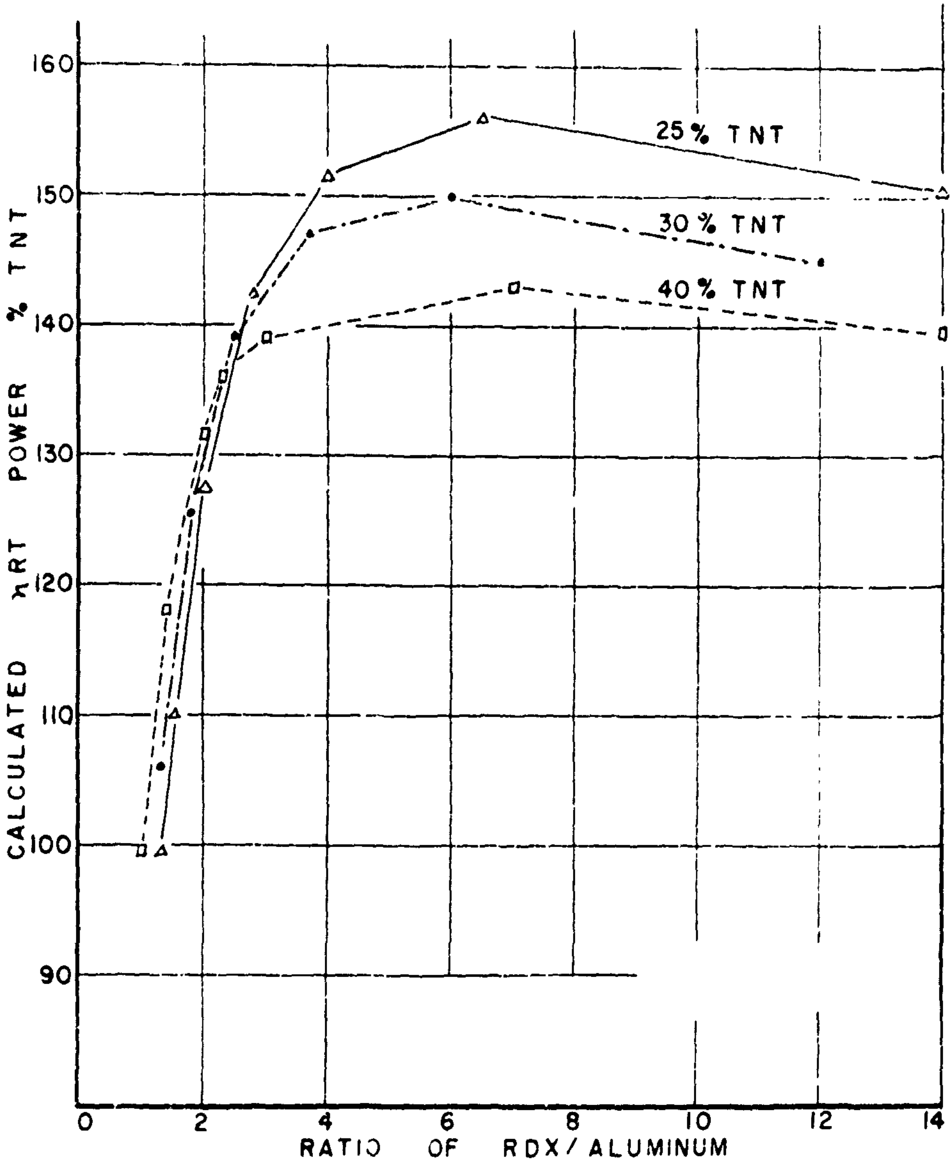

Fig 8 Relationship of RDX/Al Ratio (by Weight) to the ηRT Power Obtainable from Torpex-Type Formulations

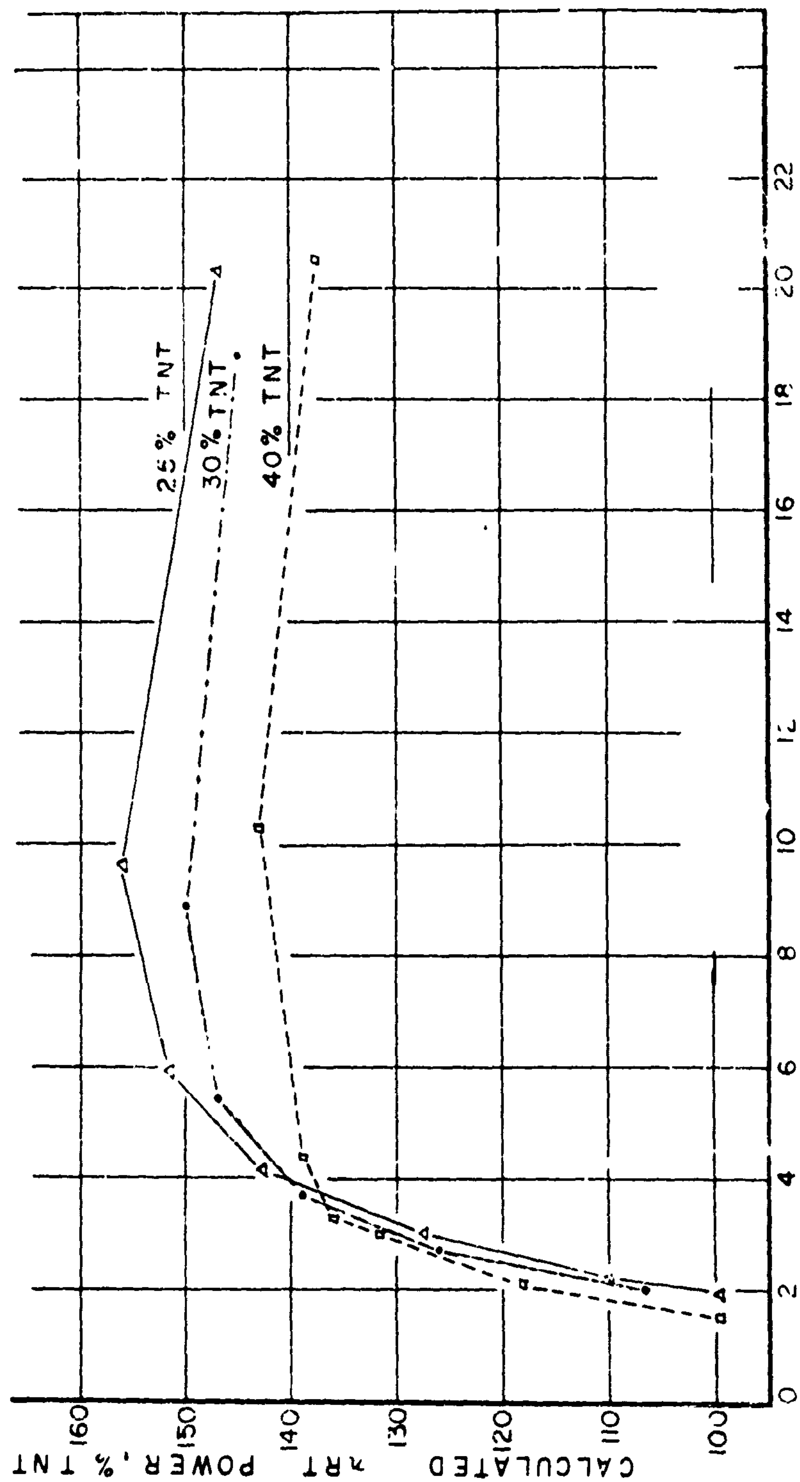

Fig 9 Relationship of RDX/Al (by Volume) to the nRT Power Obtainable from Torpex Formulations

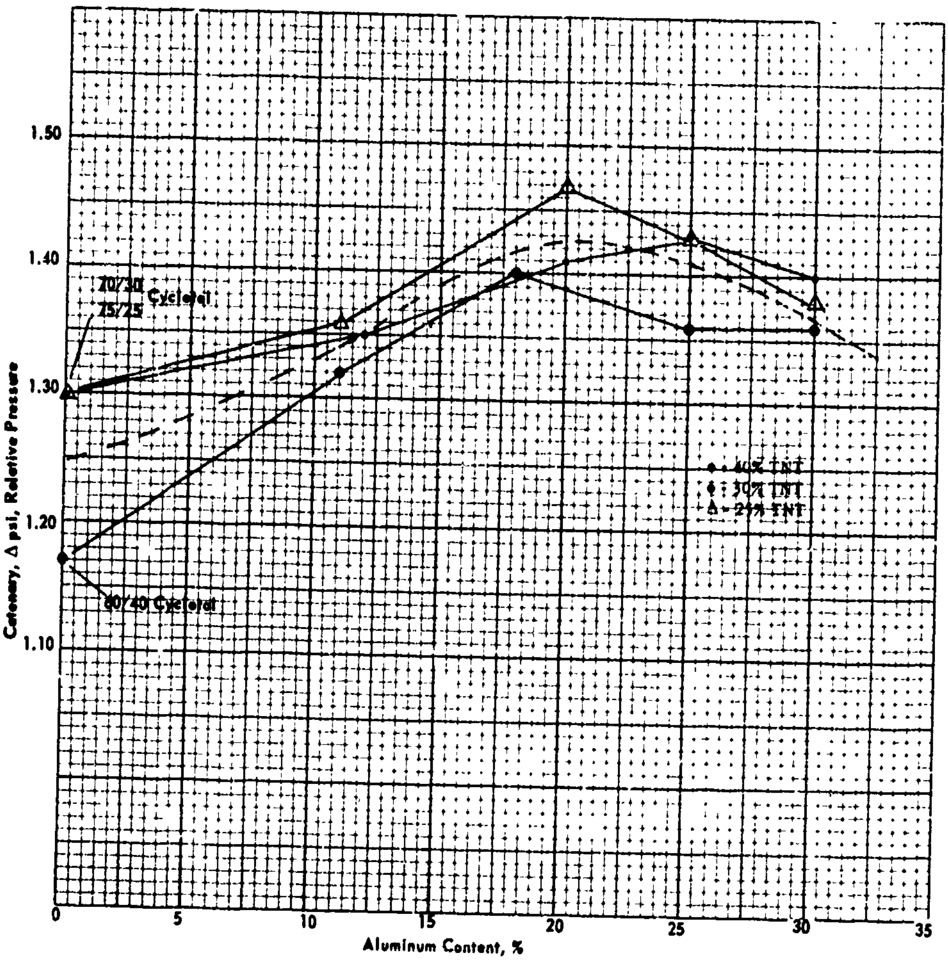

Fig 10 Relationship between the Blast Peak Pressure of One-Pound Bare Spherical Charges and Aluminum Content of the RDX/TNT/Al System

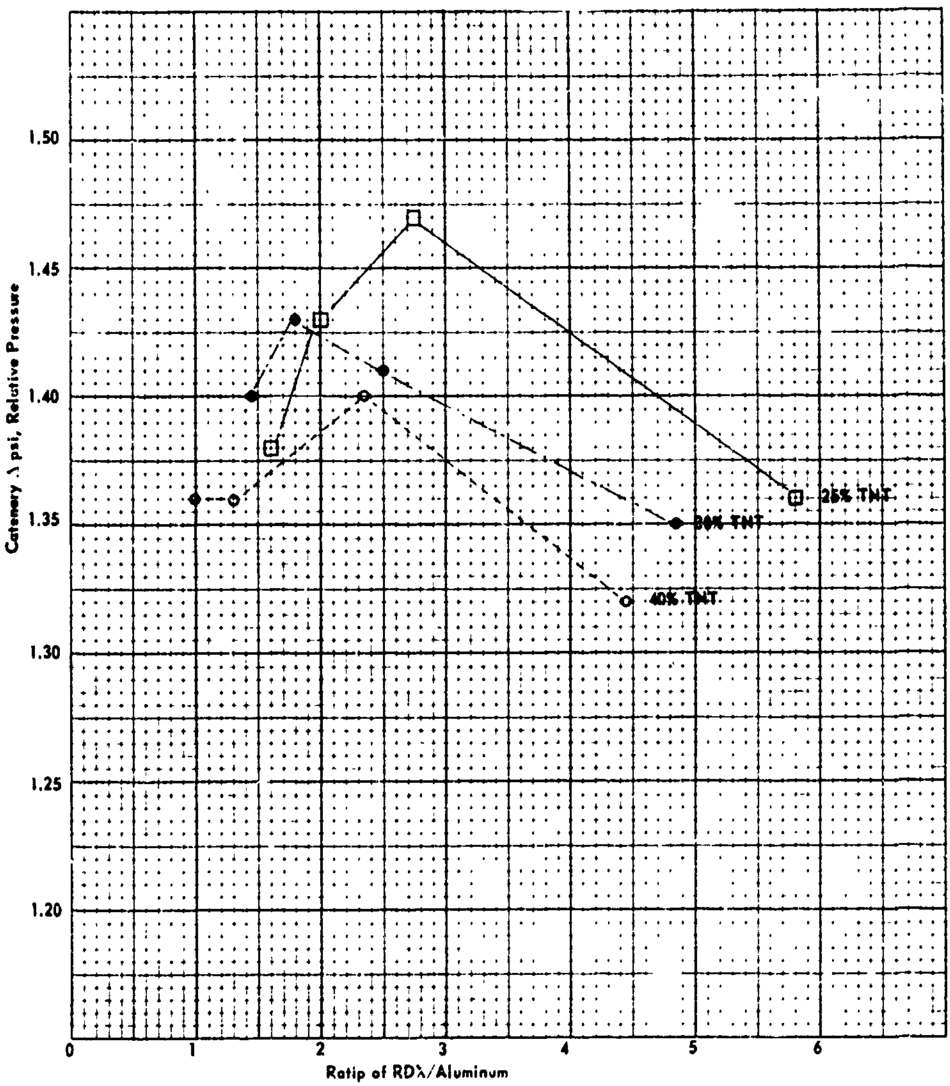

Fig 11 Relationship of the RDX/Aluminum Ratio to the Blast Peak Pressure of the RDX/TNT/Aluminum

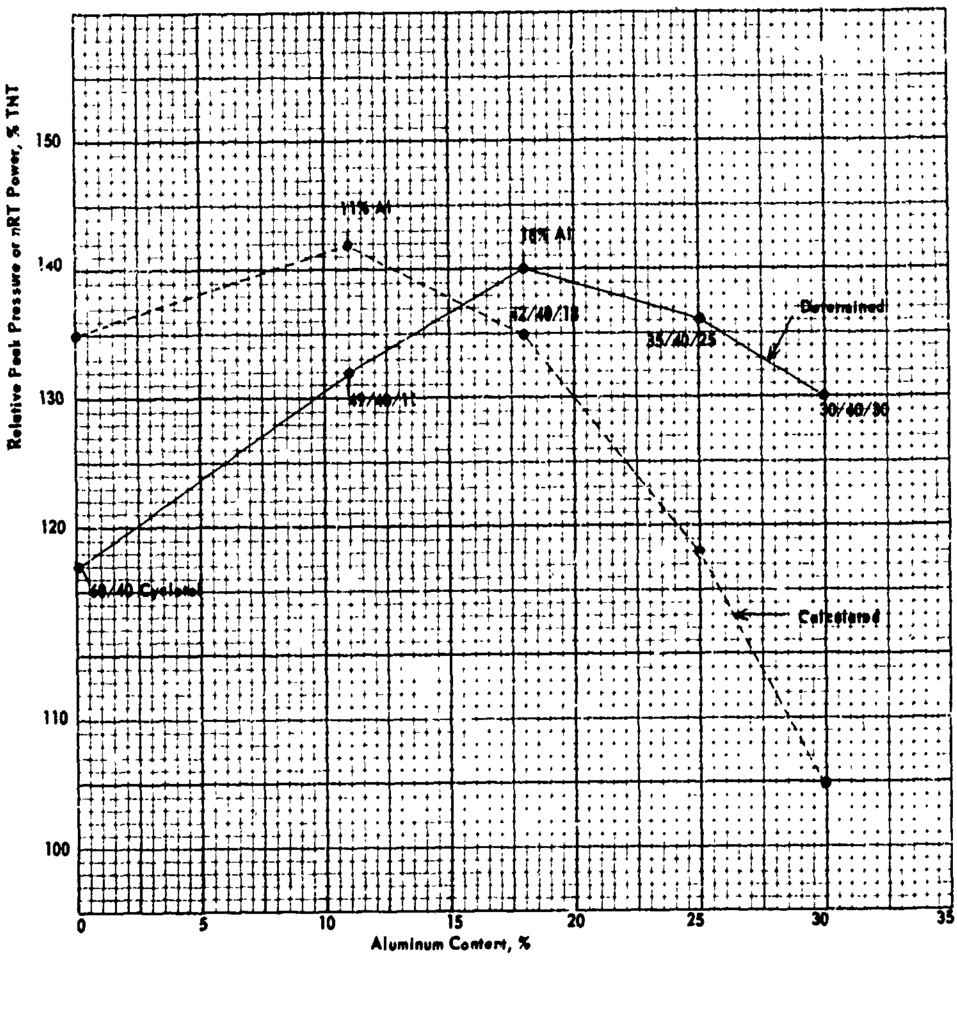

Fig 12 Comparison of Calculated nRT Power with the Actual Relative Peak Pressure Obtained with TNT Constant at 40% in the RDX/TNT/Al System

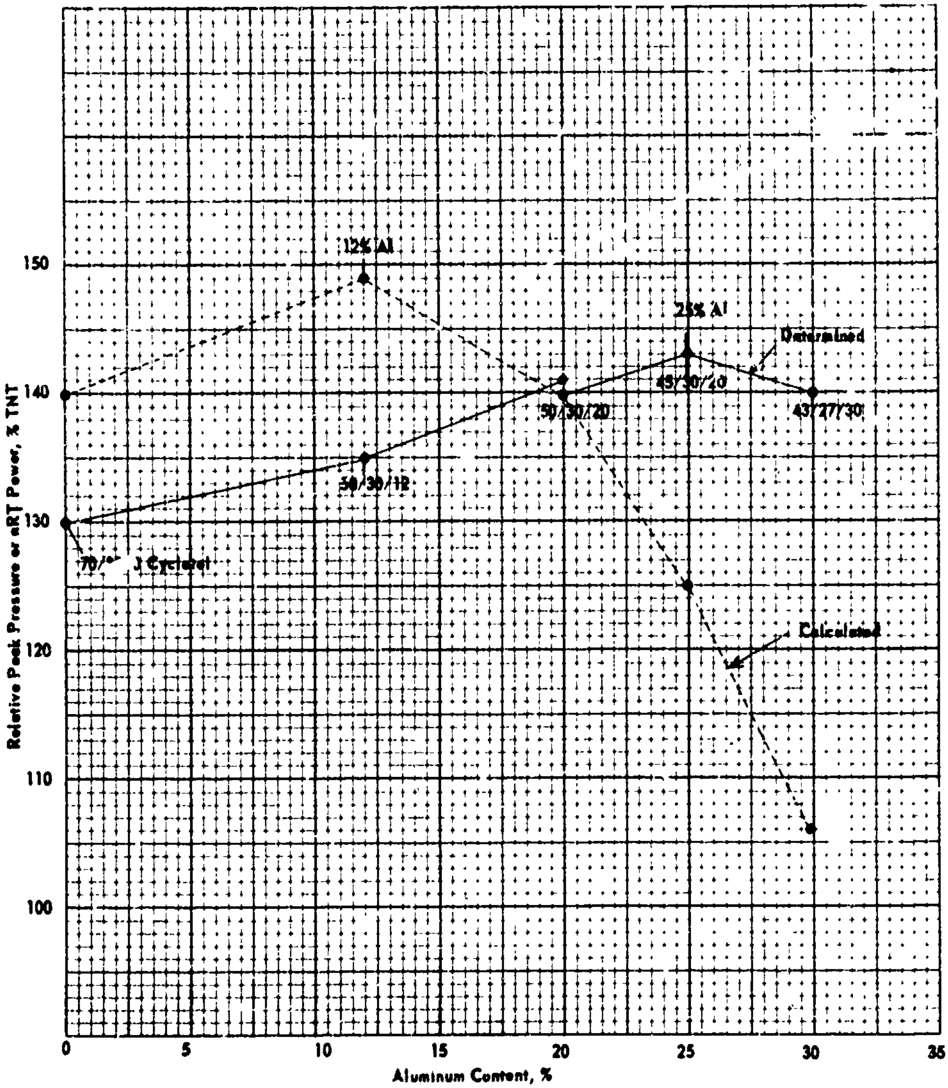

Fig 13 Comparison of Calculated nRT Power with the Actual Relative Peak Pressure Obtained with TNT Constant at 30% in the RDX/TNT/Al System

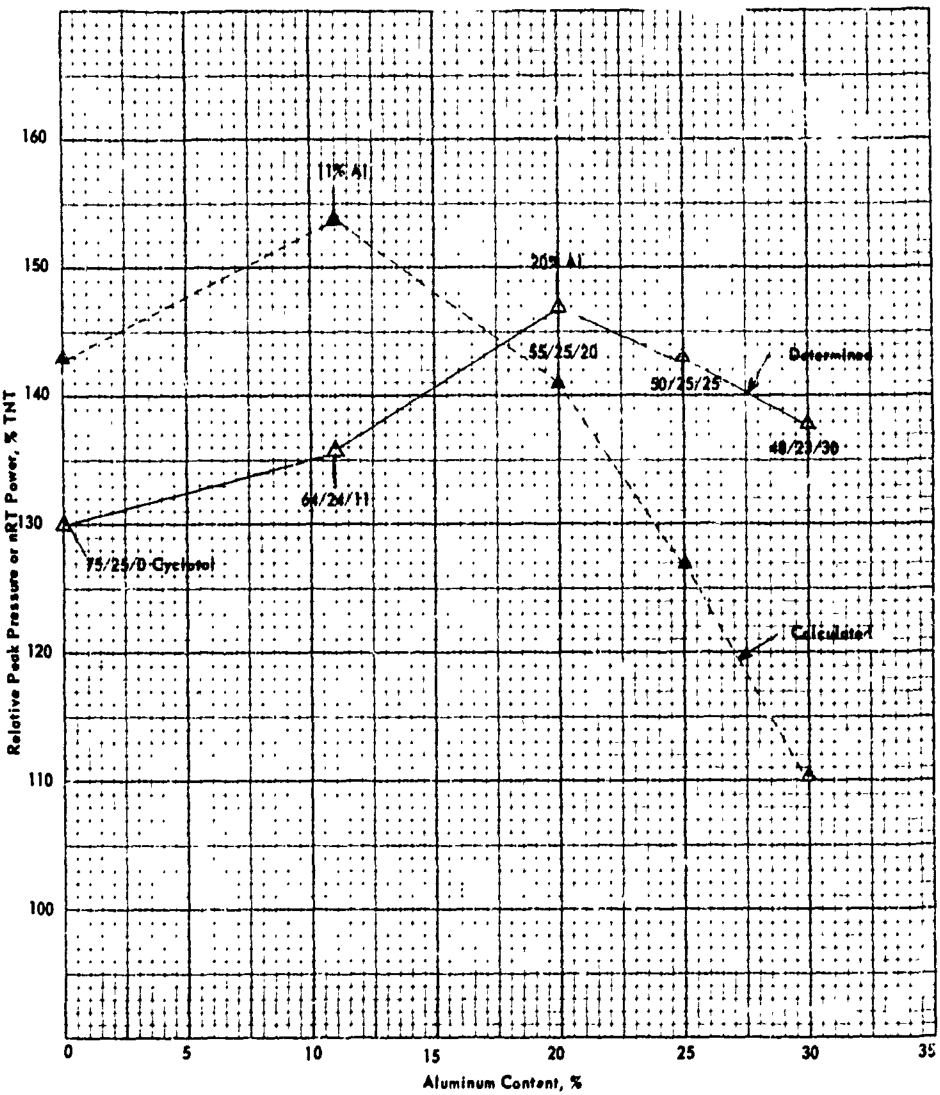

Fig 14 Comparison of Calculated nRT Power with the Actual Relative Peak Pressure Obtained with TNT Constant at 25% in the RDX/TNT/Al System

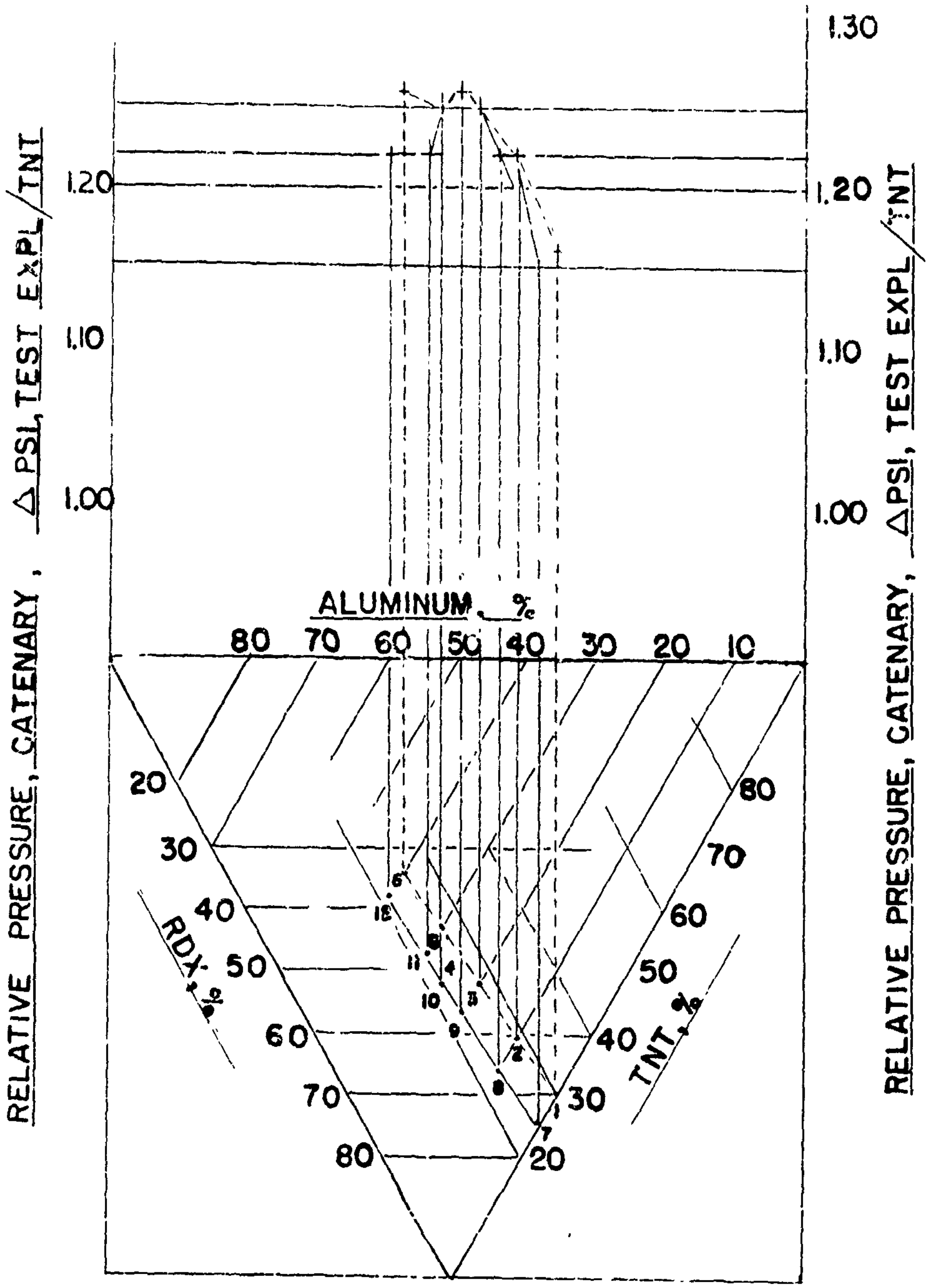

Fig 15 Three-Dimensional Diagram of the Ternary System RDX/TNT/Al vs Peak Pressure

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